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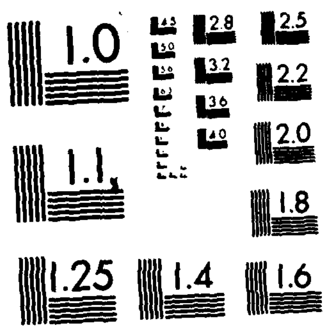

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Functional Assessment of Laser Irradiation

Annual Report

June 1977

by

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Changes in rhesus spectral and white light acuity following brief (100 msec) laser (647 nm) exposure have been measured. Permanent loss in spectral acuity occurred at an exposure level where white light acuity was still recoverable. These data suggest that postexposure spectral acuity functions reflect altered foveal function rather than total foveal disruption.

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INTRODUCTION

The adverse effects of intense irradiation on the eye has been realized for some time. The original studies were on solar retinitis (1) although it has been observed repeatedly that both morphological and functional alterations can result from very brief exposures to moderate as well as intense sources of light other than the sun. The advent of the laser and its increasing applications in the military, in medicine, and in scientific laboratories have increased the threat of ocular damage as the result of accidental exposure and the possibility of either momentary or permanent disruptions in visual performance. This project has been concerned with the adverse effects of brief, low-level laser irradiation on visual performance. Functionally derived safety standards are of prime importance since permanent disruptions in visual guided behavior can occur at irradiation levels below those in which current morphological and/or opthalmological data have been reported (2). Furthermore, morphological criteria alone tell us little about the degree or type of resultant degradation in visual performance which would be of prime military concern in missions where successful completion is dependent upon visual and/or visual motor behavior.

In a previous experiment, Zwick, Bedell, and Bloom (3) found changes in spectral acuity and spectral sensitivity after suprathreshold Q-switched ruby laser exposure (694 nm) in the absence of differences between exposed and unexposed eyes for white light background acuity targets. In a similar experiment (4), we have examined the transition from temporary to permanent loss in foveal acuity for white light background acuity targets. In this last procedure, a finer assessment of the transition between transient and permanent acuity loss could be made for foveal exposure (HeNe, 633 nm) since immediate postexposure data could be obtained. During the past project period, the advantages of both these previous experiments have been combined by measuring immediate recovery of spectral acuity. The lowest exposure level for which change from transient to permanent acuity loss occurred, using white light and spectral targets, was determined. The data indicate that the most sensitive criteria for acuity changes following laser exposure occurred when using spectral targets.

METHOD

The procedure for training and measuring transient Landolt ring acuity loss in the rhesus following brief laser exposure has been previously described (5). In the present project period, a Krypton laser (647 nm) was substituted for the helium neon laser (633 nm) previously used, so that sufficient power at the cornea would be available to expand the retinal irradiance diameter from 150 microns to 323 microns. All retinal exposures were made during threshold acuity measurements. The laser beam was aligned coaxially with a line between the artificial pupil and the gap in a specified threshold ring. Exposures of 100 msec duration were made at corneal irradiances increasing from 1 to 6 mW. The total retinal

energy at 6 mW corresponded to no more than 732 mJ/cm^2 (8.34 log troland sec). One exposure was made per test session and, at each exposure level below that which produced a permanent deficit, a minimum of four exposures were made over a period of approximately two weeks' time. If acuity did not recover within a given session (about one hour of post-exposure measurements), further exposures were discontined on subsequent sessions until evidence of full recovery at all spectral test backgrounds was achieved. The laser exposure level at which this recovery criterion failed to be achieved defined the transition between temporary and permanent acuity loss.

RESULTS

Comparisons of the transient effects following a 1 mW corneal exposure, for five spectral background targets, are shown in Figure 1. All spectral backgrounds were equated for equal energy and the subject adjusted the size of the gap in a black Landolt ring about his threshold level. The animal was exposed to a single 647 nm, 100 msec exposure over a 324 micron area centered on the fovea while in the midst of detecting the gap in a threshold Landolt target. Immediately after exposure the subject's acuity decreased to a maximum of between 70 and 80 percent of the pre-exposure level followed by a gradual recovery in visual performance over the next hour. Each curve presented in Figure 1 represents the mean of four exposure sessions. Total recovery appeared longest for the shortest wavelength background (480 nm).

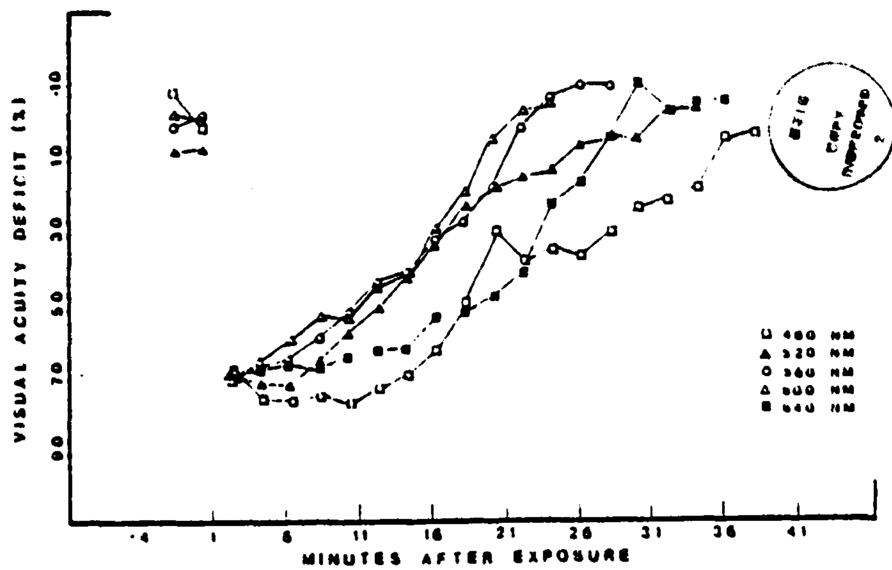

Figure 1. Percent deficit in visual acuity relative to pre-exposure acuity for various monochromatic targets following a single 1.0 mW laser exposure. The 647 nm exposure was 100 msec in

duration and irradiated a 323 micron area centered over the fovea. Exposures were made immediately following the correct detections of a 1.16 (min of arc)$^{-1}$ Landolt ring. Individual data points for each background wavelength represent the mean of four exposure sessions for each running two minutes of testing. Pre-exposure levels and variability are shown in the left hand portion of the figure for the four-minute period prior to exposure.

Statistical analyses of these data revealed no significant differences (t-Test, $p > 0.05$) between the magnitude of the initial deficit for different spectral backgrounds although statistically significant differences (t-Test, $p < 0.01$) did exist for the total duration of the recovery process for different spectral backgrounds. Most rapid recovery times in this figure can be noted for the intermediate and long wavelength test targets.

Changes in the energy of the laser exposure produced no statistically significant differences (t-Test, $p > 0.05$) in the magnitude of the initial deficits but did produce statistically significant (t-Test, $p < 0.01$)

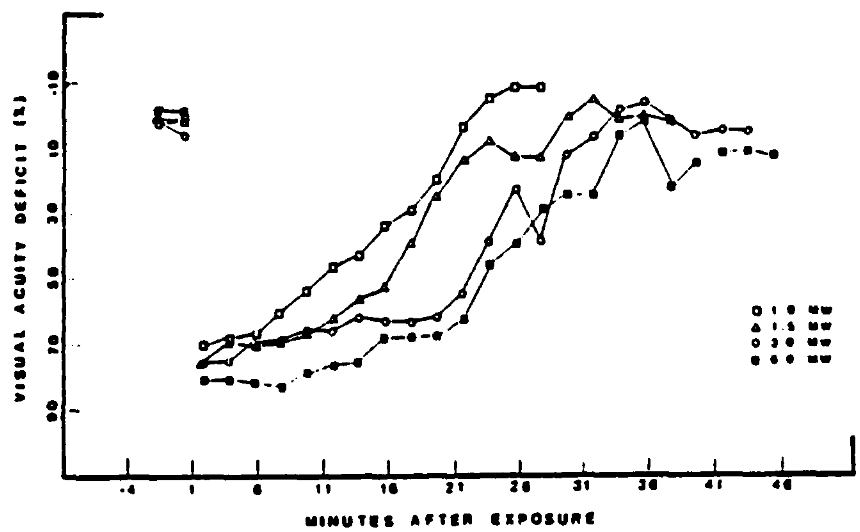

Figure 2. Percent deficit in visual acuity relative to pre-exposure acuity following various levels of 647.1 nm laser irradiation. Acuity was measured using black Landolt rings superimposed on a 560 nm background. The laser exposure was 100 msec in duration and irradiated a 323 micron area centered over the fovea. Individual data points for each power level represent the mean of four exposure sessions with exception to the data presented for 6.0 mW. At this irradiation level a permanent functional deficit was noted following the third exposure and no future

exposures were made on this subject. Pre-exposure levels and variability are shown in the left hand portion of the figure for the four-minute period prior to exposure.

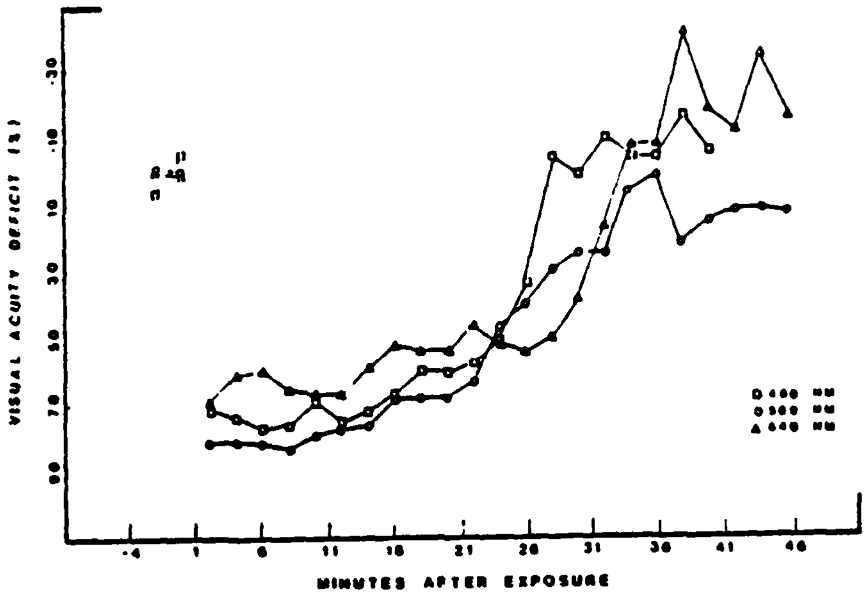

Figure 3. Percent deficit in visual acuity relative to pre-exposure acuity following three separate 6.0 mW, 647.1 nm exposures. Each curve represents the effects of exposure to a single 100 msec flash measured over an hour of postexposure testing using one of three different wavelength targets. The subject was first exposed to a 6.0 mW flash and acuity measured using 560 nm targets. Six days later the subject was exposed to a second 6.0 mW exposure, and postexposure acuity measured using 480 nm targets. The following day the subject was exposed to the final 6.0 mW, 647.1 nm flash and postexposure acuity measured using 640 nm targets.

changes in both the total time of recovery and the rate of recovery during the initial phases of the recovery process. Representative recovery functions for 560 nm test targets are presented in Figure 2 for a series of different irradiation levels beginning at 1.0 mW and increasing to 6.0 mW. Similar to the curves shown in Figure 1, each curve in this figure represents the mean of several exposure sessions with the exception of the 6.0 mW curve which represents the data from a single exposure session. For the lower exposure energies, the total recovery was relatively fast, the slope of the recovery functions relatively

steep. But as the irradiation level was increased, total time for complete recovery increased and the initial deficit remained depressed longer before recovery more gradually occurred with time.

A permanent change in visual performance and spectral acuity was produced following the third exposure at a corneal power of 6 mW. The first exposure at this corneal level was assessed with a 560 nm target background. Acuity, at this wavelength, returned to pre-exposure level and remained depressed during the next two hours of postexposure testing. Spectral acuity for this and other spectral backgrounds had returned to the pre-exposure level within 24 hours and remained at this level for the next four days of testing. On the sixth day after the first exposure, a second exposure at 6.0 mW was made, and recovery of acuity was followed with a 480 nm target background. Recovery occurred in 28 minutes after this second exposure, and no subsequent evidence of acuity loss was obtained either immediately or in a follow-up session. The third 6.0 mW exposure was assessed by 640 nm spectral background targets. Following exposure, acuity remained uniformly depressed for approximately 30 minutes before the recovery process began. Once begun, the recovery in acuity surpassed baseline acuity measurements made at this spectral background.

Measurements of the animal's spectral response function made the next 17 days showed a significant loss (t-Test, $P < 0.001$) in acuity across the entire spectrum (Figure 3). The earliest postexposure measurements showed that the entire spectral response function was severely depressed and somewhat flat across the entire visible spectrum. In following

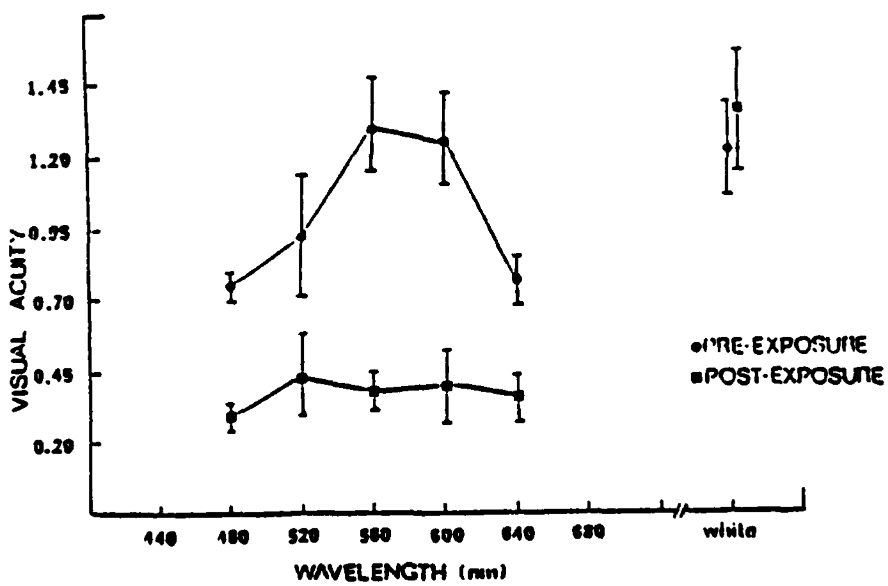

Figure 4. Spectral response curves before and after exposure to laser irradiation of sufficient power density to elicit a long-term

change in visual acuity. The pre-exposure curve was measured over several weeks of baseline testing before any laser exposures were made and each point on the curve represents the mean of several weeks of pre-exposure testing. Postexposure acuity to various background targets were measured over a 17-day period following the third exposure to a 6.0 mW, 100 msec flash of 647 nm light. All background wavelengths were equated for equal numbers of quanta and presented under maximum photic conditions. White light acuity shown on the right side of the figure was measured throughout the pre- and postexposure period. Each point on these curves represents the mean of at least four sessions and the vertical bars represent ± SD.

sessions, a slight shift in the peak of the spectral acuity was still significantly depressed from its pre-exposure level at all spectral acuity was still significantly depressed from its pre-exposure level at all spectral points tested. No permanent change in acuity ($t = 0.933$ $P < 0.3826$) measured for white light backgrounds was obtained in this animal for this exposure level.

DISCUSSION

During the current contractual period, we have examined transition from temporary to permanent changes in spectral and white light acuity following brief foveal laser exposures to 647 nm light. Permanent alterations in the ability of an animal to resolve spectral targets occurred prior to changes in white light acuity. At the minimal level where permanent change in spectral acuity occurs, acuity for white light targets remained at its baseline pre-exposure level. Previously using only white light targets, threshold for permanent functional damage occurred at 11 mW while in this project using spectral targets, threshold occurred at 6 mW suggesting that spectral acuity is a more sensitive measure of cone function than is white light acuity.

The magnitude of acuity deficits obtained with the Krypton laser (647 nm) during this contractual period compare nicely with our previous data using a HeNe source (632.8 nm). With the 632.8 nm line our retinal spot size was much smaller (150 microns) and likewise the magnitude of our retinal deficits were significantly smaller suggesting that the larger spot diameter currently employed (323 microns) brought into involvement more parafoveal cone receptors. In neither study was the amplitude of the initial acuity deficit related to the irradiation level nor to the background of the test target. The amplitude of the deficit rather appeared dependent only on the size of the retinal area irradiated.

A permanent change in spectral acuity following the third and not the first exposure to a 6 mW flash suggests possible cumulative effects of subthreshold irradiation lasting over exposure sessions. These effects are similar to our previous findings for acuity with white light backgrounds (4) in that the energy level that ultimately produced permanent

change in white light acuity also did not produce such a change on the first exposure. Recovery to white light targets failed to occur after the second exposure (11 mW for a 150μ, 633 nm flash). Similar observations have also been made for much longer repetitive exposure conditions in rhesus (6). Furthermore, the enhancement in visual function observed in the present study prior to the permanent deficit may be analogous to that reported in the ERG at levels just below those levels which produced permanent change (7).

The depressed postexposure spectral response functions may reflect either extrafoveal function, altered foveal function, or some combination of the two. A previous study (5) using small spot sizes produced less foveal involvement and smaller initial deficits for white light acuity. In this study, increasing the retinal spot size produced greater foveal involvement and significantly larger initial deficits. The data presented here indicate that total disruption of foveal function may not have occurred since the animal still had its pre-exposure capability to resolve white light targets for foveal visual criteria. As further evidence against prior extrafoveal function, the shape of the post-exposure spectral acuity function was also different from that observed elsewhere for peripheral retinal areas (8). In this latter study, central spectral response functions (foveal/macular) in the rhesus measured by static and slowly moving acuity targets were quite similar to the pre-exposure data presented in this study. More peripheral spectral response curves, as measured for rapidly moving acuity targets, demonstrated a shift in peak spectral response toward the intermediate spectral region and a more steep dropoff in the long end of the spectrum than did our postexposure spectral response functions. Hence, our postexposure spectral response functions may reflect a change that has been induced in foveal neural retinal processing systems, leaving a largely altered but still functional fovea.

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